

METEOROLOGICAL OFFICE

# THE METEOROLOGICAL MAGAZINE

VOL. 84, No. 992, FEBRUARY 1955

## RECENT SEASONAL CLIMATIC TRENDS OVER GREAT BRITAIN

By J. GLASSPOOLE, Ph.D.

While the climate of Great Britain has remained substantially the same for a long period, there are definite trends which have persisted with varying intensity and duration. Thus it can be said that our climate does not stand still but is constantly changing. These changes, or trends, become more apparent by considering 10-yr. moving averages which smooth out the variations from year to year. The curves obtained by plotting 10-yr. moving averages show maxima and minima at irregular intervals, and the amplitudes vary as well. The trends are also often different in the various seasons. On the whole the weather of the last 10 yr. was somewhat warmer, wetter and sunnier than usual. Further details of the changes are given below under the elements separately. Details of the preparation of the serial values for England and Wales, and for Scotland, for temperature, sunshine and rainfall are given in the note<sup>1</sup> on new climatological averages for Great Britain and Northern Ireland, published in the *Meteorological Magazine*.

**Temperature at sea level** (Fig. 1).—An outstanding feature of the annual-temperature curves is the increase in the decadal values from 1922–31 to 1929–38, in England and Wales from  $49.5^{\circ}$  to  $50.2^{\circ}$ F. and in Scotland from  $47.0^{\circ}$  to  $47.7^{\circ}$ F. This increase of  $0.7^{\circ}$ F. in annual temperature was due especially to that of the summer, although both the spring and autumn also showed increases; the winters on the other hand became somewhat colder during this period.

It is interesting to note that in Iceland the increase of temperature was earlier and larger<sup>2</sup>. All stations there showed a steady rise of annual temperature of about  $2.2^{\circ}$ F. from about 1916–25 to 1926–35. The rise of temperature began rather earlier in the north than in the south of Iceland, and was associated with an especially well marked rise of temperature in the winter months.

The two sets of curves for England and Wales and for Scotland show differences but on the whole the trends are very similar. The main features of the general trends over England and Wales are:—

**Spring.**—A steady increase from a minimum in 1923–32 of  $47.0^{\circ}$ F. to a maximum in 1943–52 of  $49.0^{\circ}$ F.

**Summer.**—A more rapid increase, from a minimum in 1922–31 of  $59.2^{\circ}$ F. to a maximum in 1932–41 of  $61.0^{\circ}$ F., followed by a decrease of temperature.

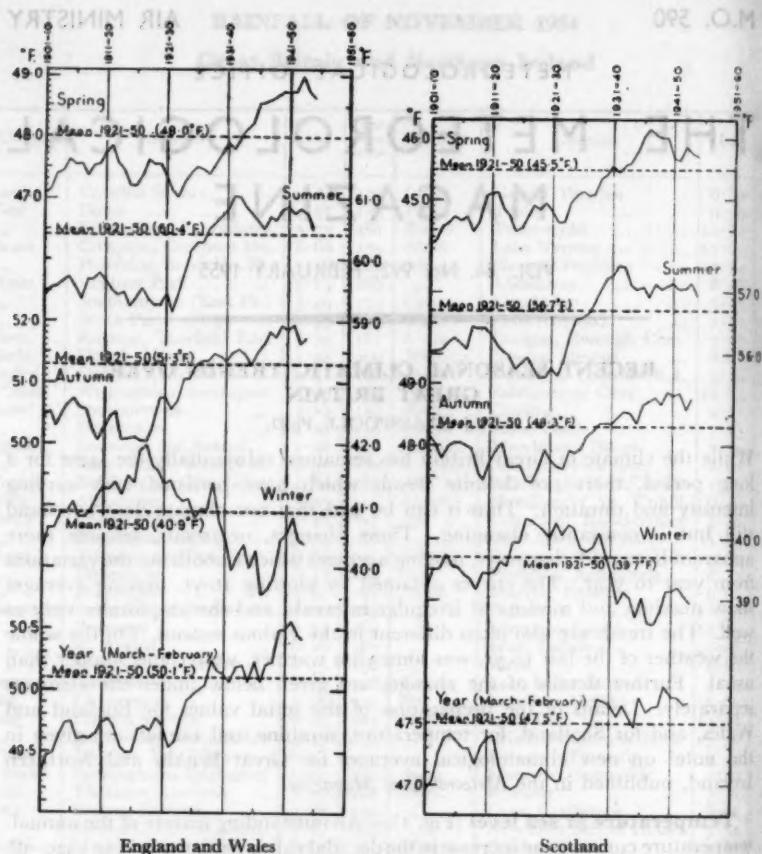


FIG. 1—10-YR. MOVING AVERAGES OF TEMPERATURE

**Autumn.**—A steady increase from a minimum in 1918-27 of 50.0°F. to a maximum in 1942-51 of 51.9°F. The rise in temperature in the autumn started earlier than with the spring or summer and continued for a longer period. The amplitude in all three seasons amounted to about 2°F.

**Winter.**—While the trends shown by the curves for the spring, summer and autumn are similar, the curve for the winter is more nearly a mirror image of the others, especially of that of the autumn. Thus the winter curve shows a general decrease from a maximum in 1918-27 of 42.0°F. to a minimum in 1937-46 of 39.6°F., a range of 2.4°F. This was followed by a rapid increase in the winter temperature until 1942-51 with 40.8°F. The increase in the winter temperature from 1937-46 to 1942-51 was 1.2°F. whereas in the same period the increase in the spring, summer and autumn was much smaller, being 0.2° or 0.3°F.

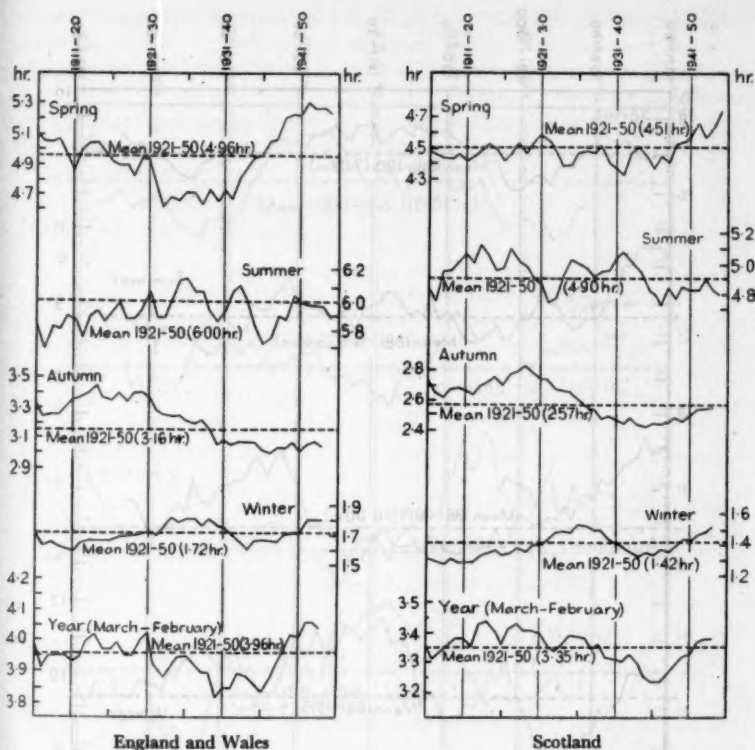


FIG. 2.—10-YR. MOVING AVERAGES OF SUNSHINE

**Relationship between temperature and sunshine.**—Comparing the curves for sunshine (Fig. 2) with those for temperature (Fig. 1) it is apparent that the trends for these two elements are dissimilar for each season and for the year. There is therefore no direct relationship between changes of sunshine amount and temperature.

**Sunshine** (Fig. 2).—The two curves for the year show a number of differences, but the general trends are similar. Both show a marked rise from 1936-45 to 1943-52, of from 3.83 to 4.06 hr./day over England and Wales and from 3.24 to 3.38 hr./day over Scotland. The two sets of curves are also similar for the seasons but there are marked differences, e.g. the summer curves from 1908-17 to 1920-29 are below average over England and Wales but above over Scotland.

The main features of the curves for England and Wales are:—

**Spring.**—A well defined increase occurred from 1932-41 to 1942-51 of from 4.67 to 5.31 hr./day. There is a similar but less marked increase over Scotland from 4.32 to 4.66 hr./day.

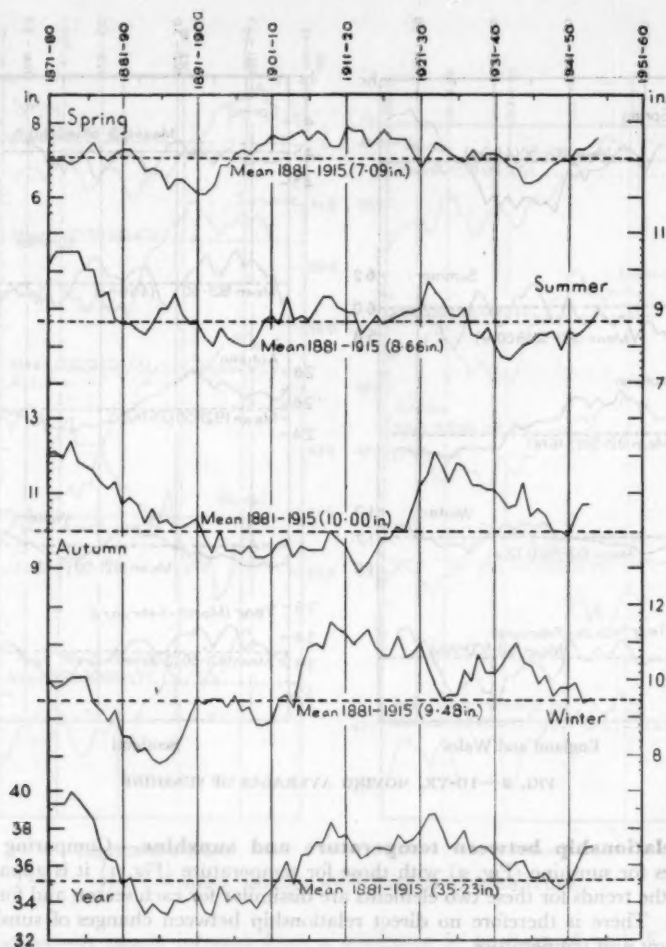


FIG. 3.—10-YR. MOVING AVERAGES OF RAINFALL IN ENGLAND AND WALES

*Summer.*—The curve shows a number of maxima and minima. The most recent extremes were 5.72 and 6.04 hr./day in 1936-45 and 1940-49 respectively.

*Autumn.*—The curve shows a steady decrease from a maximum in 1914-23 of 3.44 to a minimum in 1937-46 of 2.99 hr./day. The curve of sunshine is similar to a mirror image of the temperature curve for the autumn.

*Winter.*—The curve shows a smaller amplitude and shorter wave-length than for the autumn, the minima being in 1911-20 and 1934-43 of 1.6 and the maximum in 1924-33 of 1.8 hr./day.

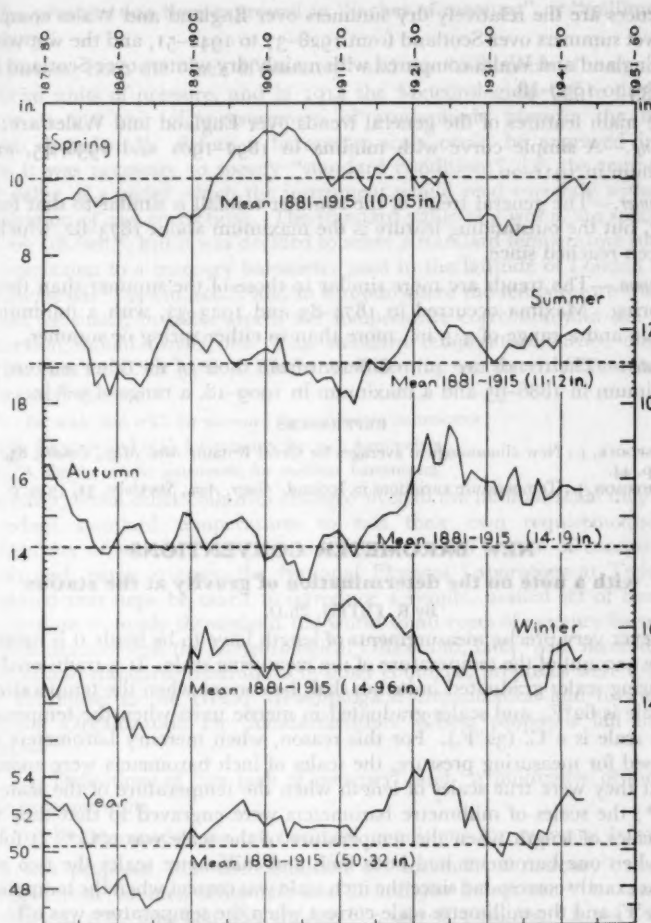


FIG. 4.—10-YR. MOVING AVERAGES OF RAINFALL IN SCOTLAND

**Rainfall** (Figs. 3 and 4).—The curves for rainfall cover a longer period than those for both temperature and sunshine. The general seasonal trends of rainfall are quite distinct from those of temperature or sunshine. The annual curves show two maxima and one minimum, the extreme range over England and Wales being given by 1874-83 with 39.9 in., 1893-1902 with 33.2 in. and 1923-32 with 38.8 in., and over Scotland by 1871-80 with 52.8 in., 1885-94 with 47.0 in. and 1923-32 with 54.9 in. The rise in the curves during recent 10-yr. periods is also noteworthy.

These two sets of curves for England and Wales, and for Scotland show differences, but on the whole the trends are similar. Some of the more striking

differences are the relatively dry summers over England and Wales compared with wet summers over Scotland from 1928-37 to 1942-51, and the wet winters over England and Wales compared with mainly dry winters over Scotland from 1924-33 to 1939-48.

The main features of the general trends over England and Wales are:—

*Spring.*—A simple curve with minima in 1892-1901 and 1936-45, and a maximum in 1911-20.

*Summer.*—The general trend of the summer rainfall is similar to that for the spring, but the outstanding feature is the maximum about 1873-82, which has not been reached since.

*Autumn.*—The trends are more similar to those of the summer than those of the spring. Maxima occurred in 1874-83 and 1923-32, with a minimum in 1913-22 and a range of 3.5 in., more than in either spring or summer.

*Winter.*—The trends are quite different from those of the other seasons, with a minimum in 1886-95 and a maximum in 1909-18, a range of 3.8 in.

#### REFERENCES

1. GLAMPOOLE, J.; New climatological averages for Great Britain. *Met. Mag., London*, **83**, 1954, p. 44.
2. EYTHORSSON, J.; Temperature variations in Iceland. *Geogr. Ann., Stockholm*, **31**, 1949, p. 36.

### NEW BAROMETER CONVENTIONS

#### with a note on the determination of gravity at the station

By R. FRITH, Ph.D.

Whenever very precise measurements of length have to be made it is necessary to take account of the temperature of the measuring scale. It is traditional that measuring scales graduated in inches shall be correct when the temperature of the scale is 62°F., and scales graduated in metric units when the temperature of the scale is 0°C. (32°F.). For this reason, when mercury barometers were first used for measuring pressure, the scales of inch barometers were engraved so that they were true scales of length when the temperature of the scale was 62°F.\*; the scales of millimetre barometers were engraved so that they were true scales of length when the temperature of the scale was 0°C.\* It follows that when one barometer had both inch and millimetre scales the two scales did not exactly correspond since the inch scale was correct when the temperature was 62°F. and the millimetre scale correct when the temperature was 0°C.

When the true height of the mercury column has been determined, making any necessary correction for the temperature of the scale, it is necessary to make further corrections for the temperature of the mercury and the value of the acceleration due to gravity ( $g$ ) at the station, since, with any given pressure, the height of a barometer column will depend upon the density of the mercury and the value of  $g$ . The conditions which, until recently, were adopted as standard were:—

*Temperature of the mercury:* 0°C. (at which the density of mercury is 13.5951 gm./cm.<sup>3</sup>)

*Gravity:* Value of  $g$  at M.S.L. in latitude 45° (taken to be 980.62 cm./sec.<sup>2</sup>).

\* This refers to the original, Fortin-type, barometer. The scales of Kew-type barometers are not true scales of length at all but are "contracted" to allow for the variation of the level of mercury in the cistern. However, the scales were still made to be correct, allowing for this contraction, at 62°F. or at 0°C. as the case may be.



The pressure was then expressed in "inches of mercury" or "millimetres of mercury".

However, both the "inch of mercury" and the "millimetre of mercury" are artificial units of pressure, and in 1914 the Meteorological Office decided to adopt as the unit of measurement of atmospheric pressure the millibar (1,000 dynes/cm.<sup>2</sup>). Before a barometer scale could be engraved in these units it was necessary to specify "standard conditions", i.e. the temperature and value of  $g$  under which the instrument would read correctly without the application of any corrections. The standard value of  $g$  was again specified as  $980.62 \text{ cm./sec.}^2$ ; but it was decided to select a standard temperature such that the correction to a mercury barometer used in the latitude of London (where  $g$  is about  $981.194 \text{ cm./sec.}^2$ ) and in a room where the temperature was  $61^\circ\text{F}$ . should be small; in other words the temperature correction and the gravity correction should cancel out. This standard temperature turned out to be  $285^\circ\text{A}$ . (i.e.  $12^\circ\text{C}$ . or  $54^\circ\text{F}$ .). There were thus in use three different standard temperatures:—

$0^\circ\text{C}$ . for scale and  $0^\circ\text{C}$ . for mercury for millimetre barometers

$62^\circ\text{F}$ . for scale and  $0^\circ\text{C}$ . for mercury for inch barometers

$285^\circ\text{A}$ . for the whole instrument for millibar barometers.

Moreover, when other countries changed over to the millibar scale they tended to adopt standard temperatures to suit their own requirements. This multiplicity of standard temperatures was a fruitful source of confusion and error; and, early in 1945, the National Physical Laboratory at Teddington suggested that steps be taken to introduce a simple, unified set of barometer conventions to apply throughout the world to all types of mercury barometers. In consultation with the Meteorological Office and, later, with meteorological services and standards institutions in other countries, proposals were drawn up and submitted to the World Meteorological Organization and to the International Organization for Standardization. These proposals fall into two parts:—

(i) Definitions of "an inch of mercury" and "a millimetre of mercury" as pressure units

(ii) Recommendations on standard conditions for mercury barometers.

It was proposed that the definition of "an inch of mercury" should be changed from "an inch of mercury at  $0^\circ\text{C}$ . and  $980.62 \text{ cm./sec.}^2$ " to "an inch of mercury at  $0^\circ\text{C}$ . and  $980.665 \text{ cm./sec.}^2$ ";  $980.665 \text{ cm./sec.}^2$  is the value for "standard gravity" which has been used universally by physicists for many years and mercury being regarded as an incompressible fluid with a density at  $0^\circ\text{C}$ . of exactly  $13.5951 \text{ gm./cm.}^3$ . A similar change was proposed in the definition of "a millimetre of mercury". These definitions have been accepted by the World Meteorological Organization and by the International Organization for Standardization, and were brought into use by the Meteorological Office on January 1, 1955. They differ from the old units by about four parts in 100,000. This difference is too small to be of any practical significance in meteorology.

It was proposed that the standard conditions for mercury barometers should be:—

Temperature (of the whole instrument):  $0^\circ\text{C}$ .

Gravity:  $980.665 \text{ cm./sec.}^2$ .

These proposals, too, have been adopted by the World Meteorological Organization. New and repaired barometers supplied to the Meteorological Office after January 1, 1955, are adjusted to these new conventions; and the National Physical Laboratory have announced that all mercury barometers tested by them after January 1, 1955, will be tested against the new conventions. The new conventions have also been issued by the British Standards Institution as a new British Standard (B.S. 2520).

Barometers adjusted to the new conventions will, of course, give precisely the same answer as barometers adjusted to the old conventions provided that the appropriate correction tables are used. Uncorrected readings will differ by about 2 mb. New basic tables are available, and these tables should be used in the preparation of correction cards for all barometers made, or repaired, after January 1, 1955. These instruments may readily be distinguished since the standard conditions are engraved on a plate immediately above the attached thermometer; they can also be distinguished by the date on the National Physical Laboratory certificate; all certificates dated January 1, 1955, or later will be based on the new conventions.

Since the standard temperature is now expressed in degrees Centigrade, the attached thermometers on Meteorological Office barometers are gradually being changed to read in degrees Centigrade instead of, as at present, in degrees Absolute.

**Revised formula for the determination of gravity at the station.**—The value of "gravity at the station" is usually computed from an empirical formula. For many years the Meteorological Office has used the formula

$$g_{\phi} = g_{45}(1 - 0.00259 \cos 2\phi),$$

where  $\phi$  is the latitude of the station. It has been known for some time that the values given by this formula are incorrect, especially at high-level stations. It has therefore been decided to use, in future, the revised formula (recommended by the World Meteorological Organization)

$$g_{\phi,h} = 980.616(1 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi) - 0.00009406h,$$

where  $\phi$  is the latitude and  $h$  is the height of the station in feet.

This new formula has been used in the preparation of the new tables necessitated by the introduction of the new barometer conventions. In addition, strictly, all existing barometer correction cards should be recomputed. Fortunately this is not really necessary and the following simpler procedure has been adopted by the Meteorological Office with effect from January 1, 1955:

At stations where the error due to the use of the old gravity formula does not exceed 0.05 mb. no change is being made.

At stations where the error lies between 0.06 and 0.15 mb. every entry on the correction card is being changed by 0.1 mb.

And so on for stations with greater errors.

As a result, barometer readings at stations in the British Isles whose height exceeds 675 ft. were all reduced by 0.1 mb. with effect from January 1, 1955. There was no change at stations below 675 ft. At some high-level stations overseas readings were reduced by as much as 0.5 mb.



[To face p. 40



CIRROCUMULUS CLOUD AT CRANWELL, NOVEMBER 15, 1954  
(see p. 60)

To face p. 91]



CIRROCUMULUS CLOUD AT CRANWELL, NOVEMBER 15, 1954  
(see p. 60)

A  
It  
dep  
two  
stra  
Va  
sur  
to  
wes  
win  
A  
cas  
ston  
but



D  
pre  
laye  
T  
occe  
ligh  
also  
whe  
equ  
it w  
who  
I  
gre  
and

## A NOTE ON SUMMER WEATHER IN THE EUPHRATES VALLEY

By A. F. JENKINSON, B.A.

It has been shown by Jenkinson<sup>1</sup> that during summer the passage of depressions eastwards over the Ukraine is followed, after an interval of about two days, by the arrival of colder air over Lower Egypt, which clears away low stratus there. The same air mass, much modified, also reaches the Euphrates Valley, with an increase in the north-westerly gradient winds giving strong surface winds and sandstorms. On the average a fall of pressure at Odessa to 1009 mb. will cause the wind at 1,000 ft. at Shaibah to increase to north-westerly 40 kt., and a rise of pressure at Odessa to 1017 mb. will cause the wind at 1,000 ft. at Shaibah to decrease to 10 kt.

A south-easterly thermal wind, associated with the colder air over the eastern Mediterranean, develops over the Euphrates Valley during the sand-storm period. The air in the layers to 800 mb. is somewhat cooler than usual, but above 700 mb. the air is warmer than usual.

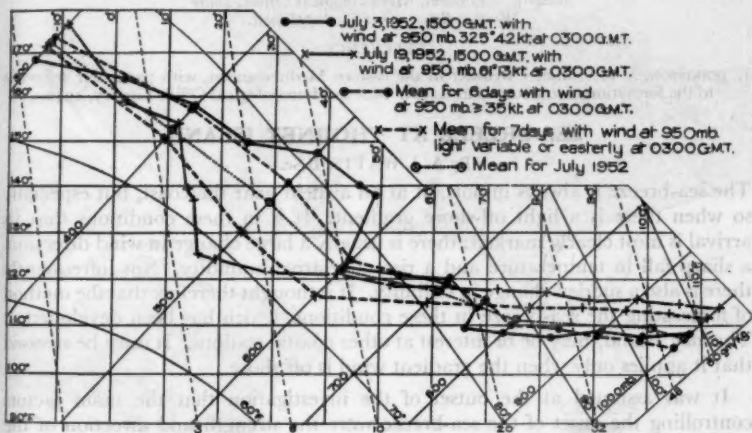


FIG. 1—TEPHIGRAMS OF RADIO-SONDE ASCENTS AT HABBANIYA, JULY 1952

During the periods of light surface wind a moderate westerly thermal wind prevails, and above the lower layers which are warmer than usual there is a layer which is colder than usual.

Typical tephigrams for Habbaniya at 1500 G.M.T. during July 1952 on an occasion of strong north-westerly wind and sandstorms (July 3) and one of light wind from an easterly point (July 19) are shown in Fig. 1. This diagram also shows tephigrams of the mean conditions for the six days of that month when the wind at 950 mb. at Habbaniya at 0300 G.M.T. was greater than or equal to 35 kt. from a north-westerly direction, and for the seven days when it was light variable or easterly. The tephigram of mean conditions for the whole month at 1500 G.M.T. is also shown.

It will be seen that the variability of temperature during the month is much greater in the layer between 550 and 450 mb. than it is in the layers below and above these levels. The standard deviations of temperature at 1500 G.M.T.

for July 1952 and for July 1951-52 combined, shown in Table I, confirm this conclusion.

The mean vector wind at 500 mb., for the six days with the wind at 950 mb. greater than or equal to 35 kt., was  $270^{\circ}$  2 kt., and for the seven days with the wind at 950 mb. light or easterly  $270^{\circ}$  25 kt.

TABLE I—STANDARD DEVIATION OF TEMPERATURE AT HABBANIYA

Time of observation: 1500 G.M.T.

	July 1952	July 1951-52
mb.	<i>degrees Centigrade</i>	
300	1.6	...
400	1.9	1.8
500	3.6	2.9
600	2.4	1.9
700	1.8	...
850	1.7	...
Surface	1.6	...

Authority.—London, Meteorological Office. *Daily Weather Report, Overseas Supplement.*

#### REFERENCE

- JENKINSON, A. F.; Summer weather in the eastern Mediterranean, with particular reference to the formation of low stratus in Egypt. MS. in Meteorological Office Library, 1942.

### SEA-BREEZE AT THORNEY ISLAND

By A. J. WATTS, B.Sc.

The sea-breeze is always important at an airfield near the coast, but especially so when there is a light off-shore gradient. It is in these conditions that its arrival is most clearly marked: there is usually a large change in wind direction, a sharp fall in temperature and a rise of relative humidity. Not infrequently there is also a sudden change in visibility. It is thought therefore that the method of forecasting the sea-breeze in these conditions, which has been developed at Thorney Island, may be of interest at other coastal stations. It must be stressed that it applies only when the gradient wind is off shore.

It was assumed at the outset of the investigation that the main factors controlling the onset of the sea-breeze were the strength and direction of the gradient wind, and the difference of temperature between land and sea. The first requirement was therefore to obtain a satisfactory measure of these quantities.

**Excess land temperature.**—The temperature over land was taken as the value recorded by a distant-reading thermograph mounted on the roof of the meteorological office (47 ft. above ground level and three miles from the open sea). As there is a wide strip of low flat country surrounding the station (see Fig. 1), all of it very similar to the airfield, it is thought that this temperature should be fairly representative of the neighbourhood.

The inshore sea-surface temperature was taken as the weekly mean value, taken at high water by means of a Kent thermograph, the bulb of which is situated just within the entrance to Chichester Harbour (two miles south of the office) and 2 ft. below the sea surface.

In what follows, the excess land temperature is the air temperature minus the sea-surface temperature both as defined above. It is evidently not an ideal parameter for our present purpose, but appeared the best available. It was,

indeed, fortunate that the inshore sea temperatures were available, since otherwise it would have been necessary to rely on published mean sea temperatures<sup>1</sup>. The differences are considerable. In June 1952, for instance, the mean inshore temperature was 5°F. above the published mean value, while in February 1952 it was 10°F. below the published mean. It will be shown presently that 10°F. is more than enough to produce a sea-breeze, so that sea-breezes can occur on many days when, if one relied on the mid-channel mean

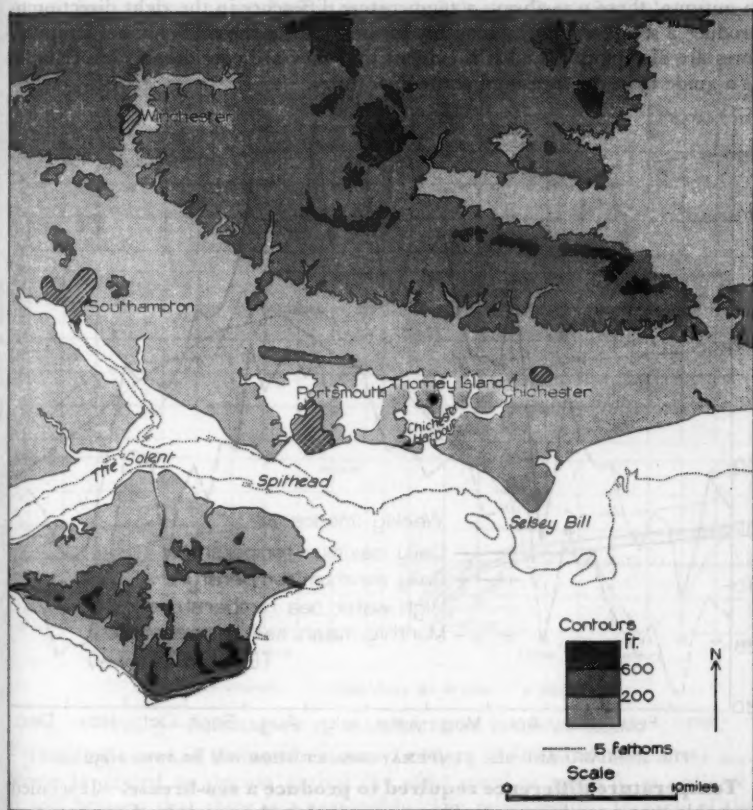


FIG. 1—AREA ROUND THORNEY ISLAND

values of temperature one would rule them out. For example, on January 20, 1953, a sea-breeze occurred, and brought a sharp fall in visibility; yet the maximum air temperature at Thorney Island was only 47°F., which is the mean mid-channel sea temperature for the month. Evidently the sea-breeze was possible only because the inshore water was colder than this.

The difference between inshore and mid-channel temperatures is particularly well marked in this district, where there are wide tidal mud-flats and sand-flats. The water is very quickly warmed during a summer day by flowing over mud

for July 1952 and for July 1951-52 combined, shown in Table I, confirm this conclusion.

The mean vector wind at 500 mb., for the six days with the wind at 950 mb. greater than or equal to 35 kt., was  $270^{\circ}$  2 kt., and for the seven days with the wind at 950 mb. light or easterly  $270^{\circ}$  25 kt.

TABLE I—STANDARD DEVIATION OF TEMPERATURE AT HABBANIYA

Time of observation: 1500 G.M.T.

	July 1952	July 1951-52
mb.	<i>degrees Centigrade</i>	
300	1.6	...
400	1.9	1.8
500	3.6	2.9
600	2.4	1.9
700	1.8	...
850	1.7	...
Surface	1.6	...

Authority.—London, Meteorological Office. *Daily Weather Report, Overseas Supplement.*

#### REFERENCE

1. JENKINSON, A. F.; Summer weather in the eastern Mediterranean, with particular reference to the formation of low stratus in Egypt. MS. in Meteorological Office Library, 1942.

### SEA-BREEZE AT THORNEY ISLAND

By A. J. WATTS, B.Sc.

The sea-breeze is always important at an airfield near the coast, but especially so when there is a light off-shore gradient. It is in these conditions that its arrival is most clearly marked: there is usually a large change in wind direction, a sharp fall in temperature and a rise of relative humidity. Not infrequently there is also a sudden change in visibility. It is thought therefore that the method of forecasting the sea-breeze in these conditions, which has been developed at Thorney Island, may be of interest at other coastal stations. It must be stressed that it applies only when the gradient wind is off shore.

It was assumed at the outset of the investigation that the main factors controlling the onset of the sea-breeze were the strength and direction of the gradient wind, and the difference of temperature between land and sea. The first requirement was therefore to obtain a satisfactory measure of these quantities.

**Excess land temperature.**—The temperature over land was taken as the value recorded by a distant-reading thermograph mounted on the roof of the meteorological office (47 ft. above ground level and three miles from the open sea). As there is a wide strip of low flat country surrounding the station (see Fig. 1), all of it very similar to the airfield, it is thought that this temperature should be fairly representative of the neighbourhood.

The inshore sea-surface temperature was taken as the weekly mean value, taken at high water by means of a Kent thermograph, the bulb of which is situated just within the entrance to Chichester Harbour (two miles south of the office) and 2 ft. below the sea surface.

In what follows, the excess land temperature is the air temperature minus the sea-surface temperature both as defined above. It is evidently not an ideal parameter for our present purpose, but appeared the best available. It was,



indeed, fortunate that the inshore sea temperatures were available, since otherwise it would have been necessary to rely on published mean sea temperatures<sup>1</sup>. The differences are considerable. In June 1952, for instance, the mean inshore temperature was 5°F. above the published mean value, while in February 1952 it was 10°F. below the published mean. It will be shown presently that 10°F. is more than enough to produce a sea-breeze, so that sea-breezes can occur on many days when, if one relied on the mid-channel mean

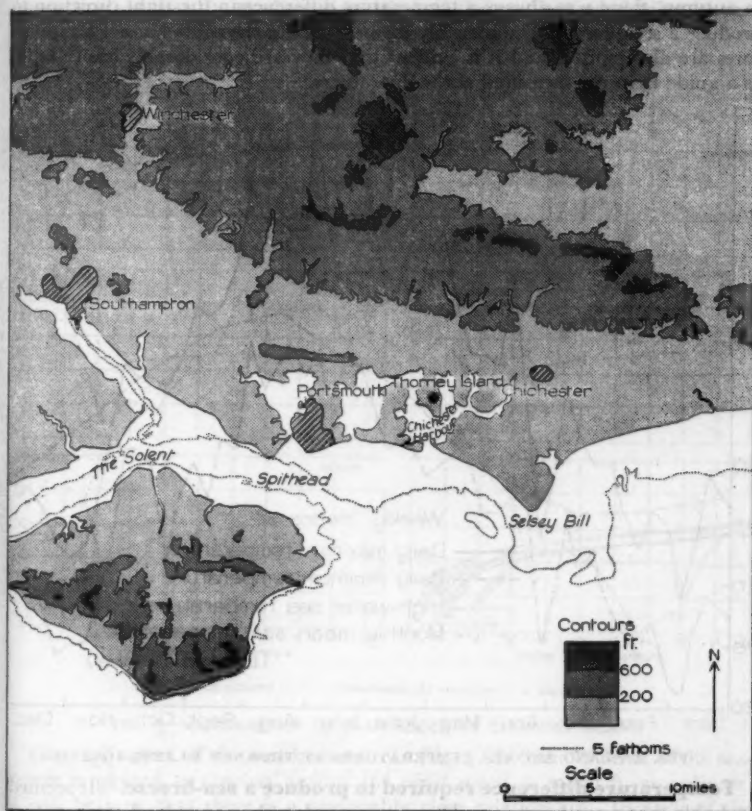


FIG. 1—AREA ROUND THORNEY ISLAND

values of temperature one would rule them out. For example, on January 20, 1953, a sea-breeze occurred, and brought a sharp fall in visibility; yet the maximum air temperature at Thorney Island was only 47°F., which is the mean mid-channel sea temperature for the month. Evidently the sea-breeze was possible only because the inshore water was colder than this.

The difference between inshore and mid-channel temperatures is particularly well marked in this district, where there are wide tidal mud-flats and sand-flats. The water is very quickly warmed during a summer day by flowing over mud

heated by the sun and, conversely, it can be rapidly cooled in winter by flowing over mud previously exposed to nocturnal radiation. For example, in summer, the water temperature at low tide (when the water around the thermometer has recently drained off the flats) is often more than  $10^{\circ}\text{F.}$  warmer than at the preceding high tide.

Fig. 2 shows the weekly mean values of maximum air temperature at Thorney Island and of inshore sea temperature during 1952. It will be seen that, except in autumn, there was always a temperature difference in the right direction to produce a sea-breeze. The monthly mean values of the mid-channel temperatures are also plotted, and it is evident that they are considerably less reliable as a guide than the measured sea temperatures.

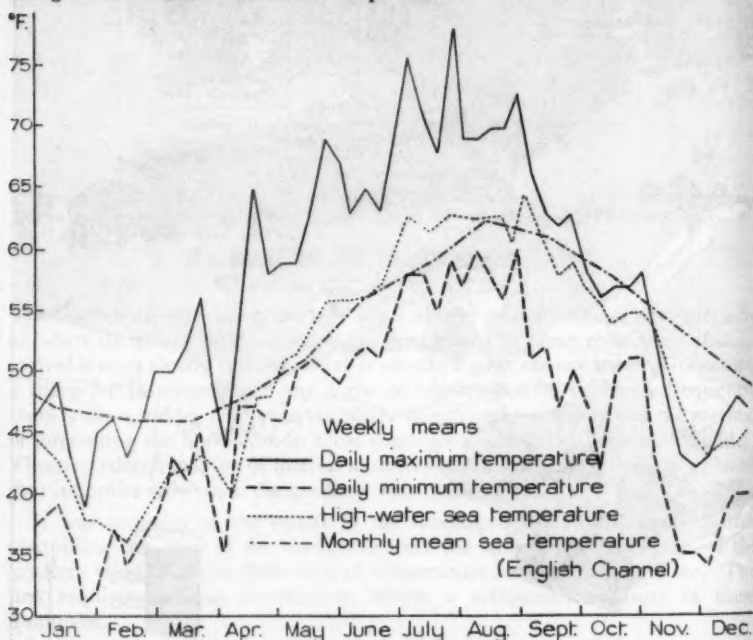


FIG. 2—LAND AND SEA TEMPERATURES AT THORNEY ISLAND, 1952

**Temperature difference required to produce a sea-breeze.**—It seemed probable that a sea-breeze would not occur unless the excess land temperature exceeded a certain critical value, and further, that this value would depend on the strength of the opposing gradient wind. To test this, occasions in the years 1951–54 on which there was an off-shore gradient wind of less than 25 kt. and on which there was a positive excess land temperature were plotted in Fig. 3. The ordinate is the wind at 3,000 ft., estimated from the radar-wind ascents at Larkhill or Crawley, and the abscissa is the excess land temperature. The observations are divided into five groups according to wind direction at 3,000 ft. The mean sea-breeze direction was found to be  $190^{\circ}$  and five arbitrary sectors were fitted about the reciprocal direction to embrace the sector  $280^{\circ}$  to  $89^{\circ}$ . It will be seen at once that a critical line can be drawn separating the

occasions when a sea-breeze did occur from those when it did not. The curves of Fig. 3, therefore, provide a simple and quite reliable method of determining whether or not a sea-breeze will occur.

Certain of the cases shown in Fig. 3 are classed as "marginal". In these, the wind fluctuates between off shore and on shore. The mechanism seems to be as follows: temperature rises over land, and a sea-breeze is induced; this brings in cooler air which, in the marginal case, is sufficiently dense to prevent further convection, so that the sea-breeze ceases, and the gradient wind takes control again. Evidently this sequence can occur several times in succession.

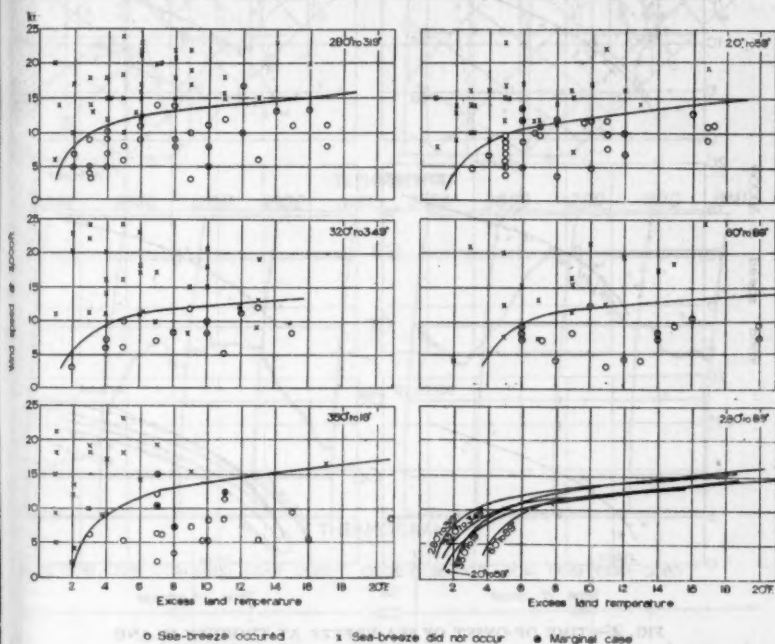


FIG. 3—OCCURRENCE OF SEA-BREEZE AT THORNEY ISLAND

**Time of onset of the sea-breeze.**—In Fig. 4, the time of onset of the sea-breeze is plotted as abscissa against the wind speed at 3,000 ft. as ordinate. It will be seen that there is a reasonably close relationship. In each of the diagrams of Fig. 4, a curve has been fitted to the observations, and in some 69 per cent. of the occasions the actual times of onset are within an hour of the time given by the curve. The observations in Fig. 4, as in Fig. 3, are divided into the same five groups as before.

The winds used were estimated from the radar-wind ascents at Larkhill or Crawley. Considerable inaccuracies are inherent in this process, and it is thought that, if winds could have been measured at Thorney Island and nearer to the time of onset, a considerably better fit would have resulted. Certainly the majority of the points which are very far from the curves represent occasions when the gradient wind was changing rapidly and was therefore difficult to estimate.

Attempts have been made to improve the fit of the points by using some other zero for the time scale than midnight. Trials have been made using as zero sunrise and the time at which air temperature became equal to sea temperature, but no improvement resulted. An equally surprising result was that, so far as could be judged, the magnitude of the excess land temperature had no bearing on the time of onset of the sea-breeze.

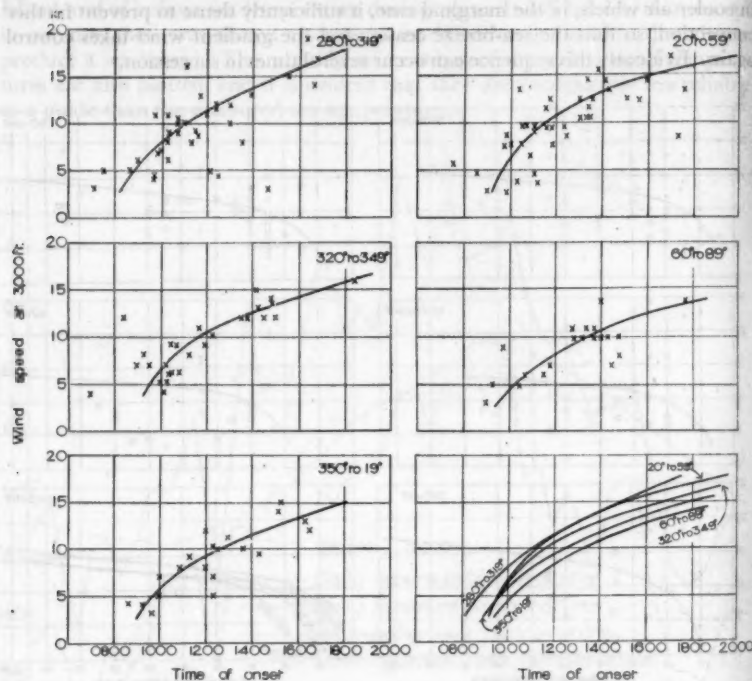
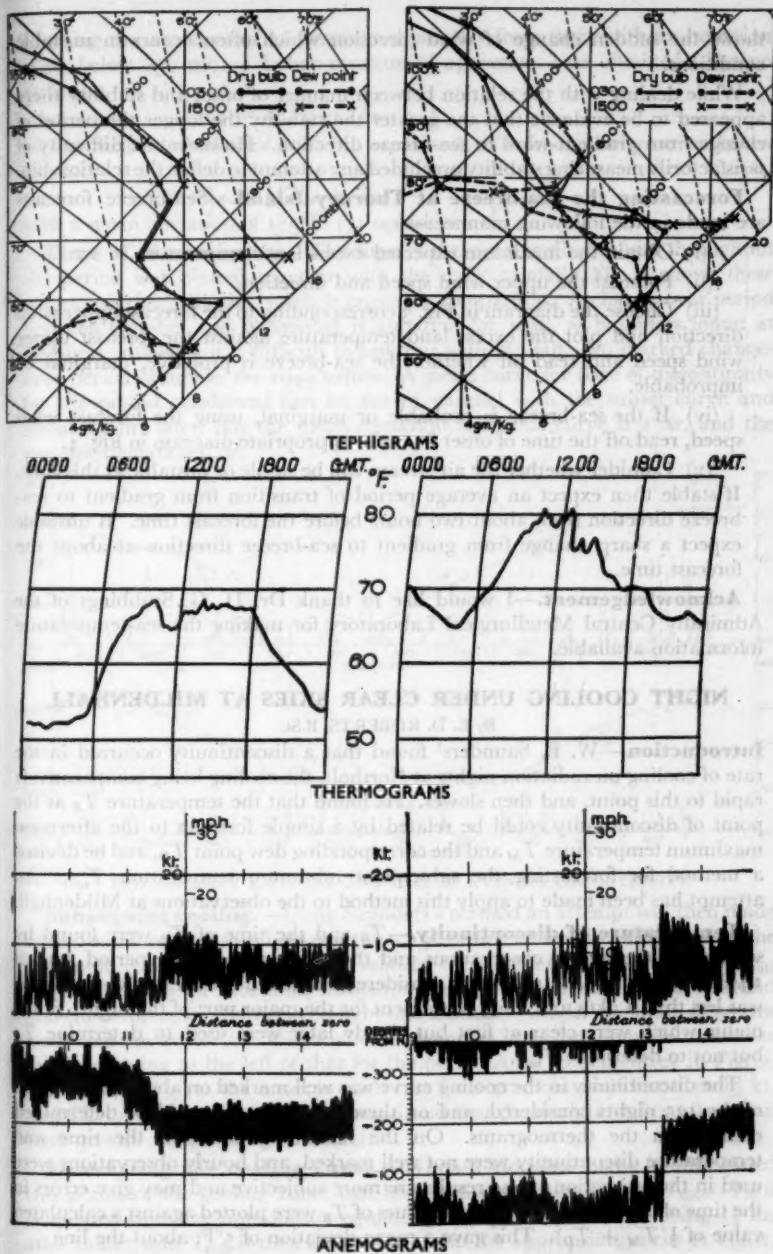


FIG. 4—TIME OF ONSET OF SEA-BREEZE AT THORNEY ISLAND

**Effects of stability.**—When conditions are thermally stable, the sea-breeze arrives with a gradual change of wind; but in unstable conditions it arrives suddenly. Out of 58 occasions of sea-breeze in 1952, 26 occurred when convection was possible to a height of at least 10,000 ft., and the average time taken to establish the sea-breeze was 21 min.; in 16 of these cases the time taken was 10 min. or less. On the remaining 32 days, when convection was not possible, the average time was 117 min.

Typical anemograms are shown in Fig. 5. They are taken from the pressure-tube anemograph at Thorney Island, the head of which is 75 ft. above sea level. The Larkhill upper air temperatures and Thorney Island thermograms are also reproduced.

The anemogram of June 11 shows the normal manner of onset in stable conditions with the gradual change of wind direction to 190–200°, which is the normal sea-breeze direction for this station. The anemogram for July 23



June 11, 1952 July 23, 1952  
FIG. 5—TYPICAL OCCASIONS OF SEA-BREEZE AT THORNEY ISLAND

shows the sudden change of wind direction which often occurs in unstable conditions.

While dealing with the relation between manner of onset and stability there appeared to be evidence that the greater the stability the longer the period of change from gradient-wind to sea-breeze direction. However the difficulty of satisfactorily measuring stability precluded any attempt to define the relationship.

**Forecasting the sea-breeze at Thorney Island.**—Sea-breeze forecasts are made in the following manner:—

- (i) Obtain the maximum expected excess land temperature.
- (ii) Forecast the upper wind speed and direction.
- (iii) Choose the diagram in Fig. 3 corresponding to the forecast upper wind direction and plot the excess land temperature against the forecast upper wind speed and read off whether the sea-breeze is probable, marginal or improbable.
- (iv) If the sea-breeze is probable or marginal, using the forecast wind speed, read off the time of onset from the appropriate diagram in Fig. 4.
- (v) Consider whether the air stream will be stable or unstable at this time. If stable then expect an average period of transition from gradient to sea-breeze direction from about two hours before the forecast time. If unstable expect a sharp change from gradient to sea-breeze direction at about the forecast time.

**Acknowledgement.**—I would like to thank Dr. H. G. Stubbings of the Admiralty Central Metallurgical Laboratory for making the sea-temperature information available.

## NIGHT COOLING UNDER CLEAR SKIES AT MILDENHALL

By E. D. ROBERTS, B.Sc.

**Introduction.**—W. E. Saunders<sup>1</sup> found that a discontinuity occurred in the rate of cooling on radiation nights at Northolt, the cooling being comparatively rapid to this point, and then slower. He found that the temperature  $T_R$  at the point of discontinuity could be related by a simple formula to the afternoon maximum temperature  $T_M$  and the corresponding dew point  $T_D$ , and he devised a method for forecasting the subsequent minimum temperature  $T_{min}$ . An attempt has been made to apply this method to the observations at Mildenhall.

**Temperature of discontinuity.**— $T_R$  and the time of  $T_R$  were found by scrutiny of the hourly observations and thermograms over the period August 1948 to April 1950. A night was considered suitable if the mean cloud amount was less than 1 okta and if fog was absent for the major part of the night. Some nights which were clear at first but cloudy later were used to determine  $T_R$  but not to determine  $T_{min}$ .

The discontinuity in the cooling curve was well marked on about 70 per cent. of the 125 nights considered, and on these occasions  $T_R$  could be determined easily from the thermograms. On the remaining occasions the time and temperature discontinuity were not well marked, and hourly observations were used in the estimation; these results are more subjective and may give errors in the time of  $T_R$  of as much as 2 hr. Values of  $T_R$  were plotted against a calculated value of  $\frac{1}{2}(T_M + T_D)$ . This gave a mean deviation of 5°F. about the line

$$T_R = \frac{1}{2}(T_M + T_D) - 4.$$



Treating the occasions of no inversion separately from those with an inversion at or below 850 mb., a better measure of agreement was obtained. For no inversion

$$T_R = \frac{1}{2}(T_M + T_D) - 1$$

with a mean deviation of  $2^\circ\text{F}$ . (54 occasions). For an inversion at or below 850 mb.

$$T_R = \frac{1}{2}(T_M + T_D) - 5$$

with a mean deviation of  $1.5^\circ\text{F}$ . (71 occasions).

**Time of discontinuity.**—The time of the evening discontinuity throughout the period was plotted together with the daily rainfall. Fig. 1 shows these values together with the Northolt curve for comparison. A change-over period between October and November is apparent for 1948, as Saunders found at Northolt, although it is difficult to link this with rainfall. No marked change-over period occurs in the 1949 values. A mean curve for time of discontinuity for the period considered can be drawn parallel with the sunset curve and about  $1\frac{1}{2}$  hr. later, but the mean deviation from this curve is 1 hr. and the extreme deviation 2 hr.

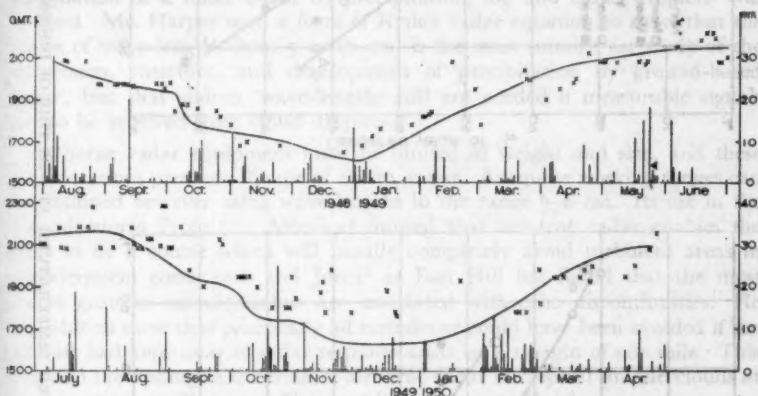


FIG. 1—DAILY RAINFALL AND TIME OF EVENING DISCONTINUITY

**Subsequent cooling.**—Using Saunders's method an attempt was then made to find some relationship between the temperature at the discontinuity and the minimum temperature. Diagrams relating the calculated values of  $T_R$  to  $T_{\min}$  were plotted as for Northolt, distinction being made between inversion and non-inversion cases and between light and moderate winds. Separate diagrams were constructed for the winter and the summer, that for the period October to March lying to the left of that for the period April to September in Fig. 2. The curve AB gives the mean in each case for a gradient wind less than 15 kt. and CD for greater than 15 kt. It was found that the deviations from the mean were greater than those for Northolt.

**Forecasting the cooling curve.**—When a cloudless night is anticipated two points of the cooling curve can be forecast, namely  $T_R$  and  $T_{\min}$ .  $T_R$  is calculated from the appropriate equation, the approximate time being  $1\frac{1}{2}$  hr. after sunset, and  $T_{\min}$  is then determined from the appropriate curve in Fig. 2, its approximate time being sunrise.

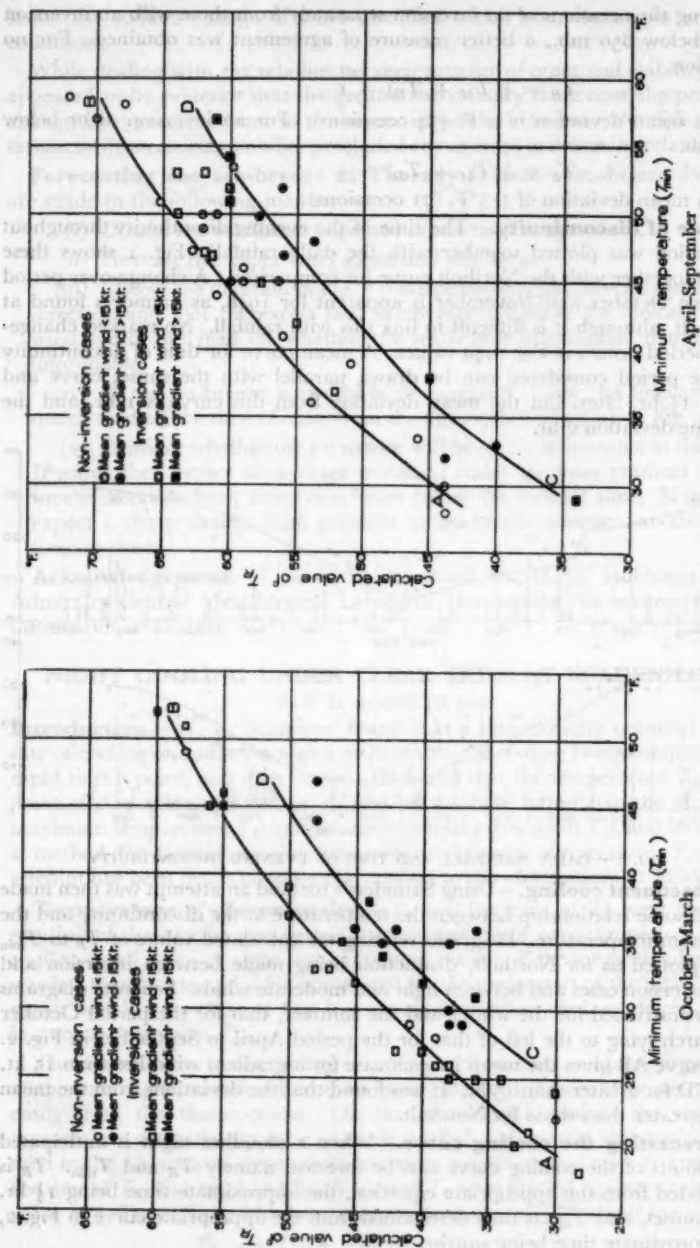


FIG. 2—RELATION BETWEEN CALCULATED TEMPERATURE AT THE TIME OF DISCONTINUITY AND THE MINIMUM TEMPERATURE

**Conclusion.**—The method has not been used for a long period at Mildenhall, but the results so far obtained have been reasonably good. However, the main sources of error in forecasting the minimum temperature remain the difficulty of estimating gradient wind and mean cloud amount during the night.

#### REFERENCE

1. BAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Quart. J. R. met. Soc.*, London, 78, 1952, p. 603.

## METEOROLOGICAL OFFICE DISCUSSION

### Weather radar in research and operations

The discussion on Monday, November 15, 1954, at the Royal Society of Arts was opened by Mr. W. G. Harper with a short survey of meteorological radar theory and practice, followed by a description of recent developments and of research uses of radar in meteorology.

The importance of Ryde's theoretical investigations of the scattering and attenuation of a radar beam by precipitation, fog and cloud droplets<sup>1</sup> was stressed. Mr. Harper used a form of Ryde's radar equation to show that the range of wave-lengths from 3 to 10 cm. is the most suitable for study of the movement, structure, and development of precipitation by ground-based radar, but that shorter wave-lengths still are needed if measurable signals are to be received from cloud droplets.

Airborne radar equipment must be limited in weight and size, and these considerations preclude the use of 10-cm. radar. Adequate working ranges can be obtained however using wave-lengths in the range 3-6 cm. Its use in the Thunderstorm Project in America<sup>2</sup> showed that airborne radar enables the pilot to fly a course which will usually completely avoid turbulent areas in thunderstorm conditions, and Jones<sup>3</sup> at East Hill has found that the most severe gusts in cumulonimbus are associated with echo discontinuities. He was able to show that practically all turbulence could have been avoided if the aircraft had kept clear of radar response areas by a margin of one mile. This was also the finding in the trials of airborne radar in tropical thunderclouds at Singapore by the Transport Command Development Unit<sup>4</sup>.

Mr. Harper produced slides to show the distinctive appearance on radar of different frontal and shower situations as seen on the 3-cm. and 10-cm. equipment at East Hill, and went on to show that simple extrapolation of the movements of precipitation areas on radar can give accurate short-period forecasts of precipitation. A six-month trial of this technique was completed in the early summer of 1954, forecasts being made independently from radar and by an experienced forecaster at Dunstable, and it was shown that radar could be a valuable aid to the forecaster. Two main reasons can be given for this, the accurate delineation of precipitation areas by radar, which is something new in meteorology, and the fact that radar takes into account the control of precipitation movements by winds aloft related to the particular precipitation mechanism. The main limitations of centimetric radar for this purpose are (i) its inability to detect drizzle and very light rain because of their small drop sizes, and (ii) in the duration of forecasts due to the speed of movement of weather echoes in relation to the range at which they can first be detected. The East Hill 10-cm. radar can detect moderate rain out to about 60 miles, and

heavy rain to about 120 miles, and forecasts from radar could rarely have been made for more than a 3-hr. period. They were frequently cut to 2 hr., occasionally to 1 hr. Radar cannot forecast development or decay of weather, but its instantaneous picture will often show if development or decay has taken place some time before this could be realized from hourly synoptic charts.

Theoretical studies have shown that non-spherical precipitation particles de-polarize the radar beam, and Labrum<sup>6</sup> in Australia, by mounting ice crystals and hemispherical water drops in a 10-cm. wave guide, has now provided the experimental confirmation of this. It is found that the radiation scattered by a partly melted ice sphere approaches that from a spherical raindrop when it has acquired only a thin skin of water. Mr. Harper showed how this effect and Ryde's radar equation successfully explain the bright band which is often observed just below the freezing level on the height-range radar display.

The value of radar in the study of precipitation processes was further illustrated from work in Canada on precipitation streaks<sup>8</sup>. Slides were shown of particularly well developed snow trails falling from what are thought to be generating elements. These elements were found often to be closely linked with frontal surfaces and to be embedded in frontal cloud. The variations in slope of the trails with height give the variations in fall velocity of the particles with height if the upper winds are known. Langleben<sup>7</sup> finds that they have a relatively uniform speed of about 3 ft./sec., and concludes that they must be snowflakes throughout the whole course of their descent. Dennis<sup>8</sup> has suggested that snow from these trails may be a factor in initiating shower activity in cumulus clouds, for the tops of precipitating cumuli are often seen to extend to the level of such trails in Canada. Radar is clearly an invaluable tool in this kind of investigation, but present radar equipment cannot define positively the nature and size of precipitation particles, and there is great advantage in the close co-operation of research aircraft and weather radar.

An accurately calibrated radar gives values of  $\Sigma Nd^6$  if the raindrops are spherical, where  $N$  is the number of drops, of diameter  $d$ , per unit volume. This is called the radar reflectivity. It is evident that large drops make an exceptionally large contribution to the received power, and that radar is extremely sensitive to changes in drop-size distribution. Best<sup>9</sup> and others have shown that there is an empirical relation between the reflectivity and the rainfall rate at the ground, but variability in the drop-size distribution can result in calculated rainfall being out by a factor of 2 even in steady-rain conditions. There are similar difficulties in measuring water content, a quantity of interest in relation to the rate of icing of aircraft.

It has been mentioned that cloud droplets can give measurable radar echoes at very short wave-lengths. As the wave-length decreases to about 1 cm. attenuation by rain increases extremely rapidly, but in addition attenuation by water vapour and atmospheric oxygen becomes pronounced; 8-mm. radar however has been shown in America to have great value as a cloud base and top indicator if used to investigate clouds vertically above the radar. Clouds containing large droplets are invariably recorded and clouds, such as altocumulus, cirrostratus and stratocumulus, containing smaller droplets or large ice crystals on about 40 per cent. of occasions. Droplets in fogs are in general too small to be detected by 8-mm. radar.

To show how wide is the field of research in which radar can be applied, Mr. Harper finally described Hewitt's work in South Africa on the radar study of lightning discharges<sup>10</sup>. Hewitt developed a drum camera which would photograph the radar return from each separate pulse of a 50-cm. radar, the pulse recurrence frequency being 1,000 per second. He was able to identify distinctive echo sequences which he associates with (a) the ionization in the main channel, and (b) the ionization resulting from a junction-streamer process in a cloud-to-ground discharge.

In the discussion which followed some exception was taken to the form of radar equation used by Mr. Harper but he was able to justify this fully in later correspondence.

*Capt. Jackson* (International Federation of Airline Pilots Association) asked about the screening effect of one cumulonimbus cloud by another. Mr. Harper said that this was negligible on 10-cm. radar, but would be noticeable on 3-cm. airborne radar because of the combined effects of range and rain attenuation. Capt. Jackson also asked whether there was any characteristic echo from hail, as had been reported from America.

*Mr. Jones* thought that the evidence of correlation between echo appearance and hail was not convincing, and was not borne out by observations in this country.

*Mr. Robinson* (Radar Research Establishment, Malvern) said that they hoped to develop a variable polarization radar which will, for example, distinguish between ice particles and supercooled water drops.

*Mr. Bigg* was disappointed at not hearing of radar means of detecting fog.

*Wg Cmdr Macintosh* (Ministry of Transport and Civil Aviation) on the other hand was very relieved to learn this. They were installing an 8-mm. radar at London Airport for the control of airport ground traffic, and had been worried lest it become ineffective in fog.

*Mr. Robinson* described investigations with an 8-mm. radar at Malvern and confirmed that radar echoes from fog were never seen. He thought it might prove possible to detect fog droplets at very short ranges on 3½-mm. radar if the very difficult problems of design at this wave-length could be overcome.

*Mr. Gold* expressed surprise at the difficulty of measuring cloud base by radar. Mr. Harper confirmed that normal weather radars, operating in the wave-length range 3-10 cm., could not detect cloud bases; 8-mm. and 12-mm. radars could do so much of the time, but the cloud base on these displays would be masked if precipitation was falling beneath it.

*Mr. Sawyer* asked whether it would be possible to remove the effect of range attenuation from the radar display. He thought it would be of special value in the case of widespread warm frontal rain, showing more accurately the intensity variations in the front. Mr. Robinson said there would be no difficulty in designing such an attenuator.

*Dr. Scrase* asked whether "angels" were ever seen at East Hill. Mr. Harper replied that they were occasionally seen on 10-cm. radar. They appeared as echo spots at heights usually from 2,000 to 5,000 ft., out to ranges of about 20 miles, and were received most frequently from clear skies after sunset. "Angels" were quite distinctive and could not be confused with weather echoes.



They are thought to be due to sharp gradients of refractive index in the atmosphere, which have not been detected by existing aircraft instruments.

Mr. Wallington spoke of the value of radar methods in short-period forecasting, and said that aircraft radar sets had been set up at some meteorological offices after the war for this purpose.

Mr. Peters thought that the results of the forecasting trial were encouraging, and mentioned the special value of radar reports on ceremonial occasions such as Trooping the Colour. He thought that more work was needed on the study of the control of precipitation movements by upper winds, and also commented on the difficulty of coding weather-echo information.

Cmdr Frankcom said that the ocean weather ships observed frontal precipitation on their radar equipment, and reported it in plain language with their routine observations.

Mr. Durward commented on the high cost of special radar equipment, and thought we should try to make more use of existing radars.

Discussion then centred around the possibility of obtaining weather-echo information from operational stations.

Mr. Bradbury described the co-operation already given in this way by Fighter-Command radar stations, who supplied weather-echo reports in NUBEX code three times a day. He had also obtained invaluable information from London Radar (London Airport) on special occasions such as fly-pasts.

Mr. Robinson thought that air-traffic-control radars would be modified in the near future to minimize rain echoes, and that it would be better to design a set specially for meteorological purposes.

Mr. Harper wondered whether it would be feasible to transmit the radar display from East Hill to the Central Forecasting Office, Dunstable by line-of-sight radio link.

Gp Capt. Fennessy (Decca Radar) said that this would cost nearly as much as a complete new radar set.

Dr. Stagg, as Chairman, then closed the discussion remarking that, despite the value of radar, forecasters need not expect to have rows of radar tubes for their use in the foreseeable future.

#### REFERENCES

1. RYDE, J. W.; The attenuation and radar echoes produced at centimetre wavelengths by various meteorological phenomena. Physical and Royal Meteorological Societies' report on "Meteorological factors in radio-wave propagation". London, 1946.
2. Washington D.C., United States Weather Bureau. The Thunderstorm. Washington D.C., 1949.
3. JONES, R. F.; Radar echoes from and turbulence within cumulus and cumulonimbus clouds. *Prof. Notes met. Off., London*, 7, No. 109, 1954.
4. FROST, R.; Cumulus and cumulonimbus cloud over Malaya. *Met. Rep., London*, 2, No. 15, 1954.
5. LABRUM, N. R.; Some experiments on centimetre-wavelength scattering by small obstacles. *J. appl. Phys., Lancaster Pa*, 23, 1952, p. 1320.
6. MARSHALL, J. S.; Precipitation trajectories and patterns. *J. Met., Lancaster Pa*, 10, 1953, p. 25.
7. LANGLEBEN, M. P.; The terminal velocity of snowflakes. *Quart. J. R. met. Soc., London*, 80, 1954, p. 174.
8. DENNIS, A. S.; Initiation of showers by snow. *J. Met., Lancaster Pa*, 11, 1954, p. 157.
9. BEST, A. C.; The size distribution of raindrops. *Quart. J. R. met. Soc., London*, 76, 1950, p. 16.
10. HEWITT, F. J.; The study of lightning streamers with 50 cm radar. *Proc. phys. Soc., London*, B, 66, 1953, p. 895.



## OFFICIAL PUBLICATION

The following publication has recently been issued:—

### METEOROLOGICAL REPORTS

No. 15—*Cumulus and cumulonimbus cloud over Malaya.* By R. Frost, B.A.

During the early summer of 1950 a series of flights through cumulus and cumulonimbus clouds over Malaya and Sumatra was made and the results are discussed in the present paper. It was found that (i) the transition from cumulus to cumulonimbus cloud occurred when the cloud tops were between 30,000 and 33,000 ft. (i.e. where the temperatures were about  $-30^{\circ}$  to  $-35^{\circ}\text{C}.$ ); (ii) cumulonimbus clouds on occasions reached the tropopause at approximately 55,000 ft.; (iii) contrary to experience in middle latitudes, radar echoes were received from cumulus clouds the tops of which were well below the  $0^{\circ}\text{C}.$  level; and (iv) practically all turbulent areas could be avoided if the radar response areas were avoided by about one mile. Observations of hail, snow, sleet, lightning and turbulence made during penetrations into cumulonimbus clouds, and which are the first of their kind in the tropics, are also discussed.

## ROYAL METEOROLOGICAL SOCIETY

### Rainfall in relation to water supply

At the meeting of the Society on November 17, 1954, Prof. P. A. Sheppard, a Vice-President, in the Chair, a symposium was held on rainfall in relation to water supply.

The broad outlines of the subject were set out by a leading water engineer, Mr. D. Halton Thompson, in describing the functions, needs, and problems of his profession, whose duty it is to see the consumer's tap never runs dry. There are two main types of water-supply systems: the overground using rivers, dammed if necessary into reservoirs, and the underground pumped through wells and bore-holes from the deep-water storage. Both types ultimately depend on rainfall, but only a fraction of rainfall is available for water supply because of losses by evaporation and transpiration and the need to maintain a proportion of river flow below a reservoir. Reservoirs must be so designed that water can be drawn off at all times at a constant rate, that they will not run dry in drought, and that excess flood water will run off without causing damage. A major problem is deciding the imposition of restrictions during a drought. In waterworks design knowledge of extremes of rainfall is essential, so that a proper balance can be maintained between cost of construction and risk of water shortage. Meteorological data presented in a practical form and analysed to enable the utmost information to be extracted are vital for the solution of the water engineer's problems.

Dr. J. Glasspoole spoke next for the meteorologists on rainfall. He dwelt first on the attainment of accuracy in rainfall measurement by the placing of rain-gauges in the proper exposures, the location of probably erroneous gauges from successive maps of annual rainfall and the need for inspection of rain-gauges. Next, he turned to the variations of annual rainfall over the British Isles. He thought there was scope for a more exact analysis of the variation of rainfall with height, because in mountainous areas records were too few for use of the planimetric method of determining rainfall by measuring areas between isohyets. He then dealt with the variability of rainfall with time with reference to the frequency of runs of wet or dry years, of droughts, and the seasonal variation of rainfall. Endeavours to unravel long-term trends in past years for forecasting the future had not been successful. Much was known of the frequency of monthly rainfalls which were of great value in estimating the reliability of rainfall; it was known for instance that it was reasonable to expect that in the driest years any group of four consecutive months will give at least 9 per cent. of the average annual rainfall at any station. Finally he referred to the information on intense falls, essential in the design of reservoir and drainage systems, for obtaining which a close network of recording rain-gauges is necessary owing to the rapid variation of rate of fall with distance. In the course of his talk he listed six ways in which the meteorologist could help the water engineer; inspection of rain-gauges, greater accuracy in the recording of snow in mountainous areas, better understanding of the physics of rain, statistical study of water data, prediction of future rainfall, determination of the area covered by heavy rain.

The third speaker was Mr. N. A. F. Rowntree describing the methods used by water engineers for assessing the available supply by means of rainfall and river-flow records. Among his points of especial meteorological interest were the desirability of publishing meteorological data for the

natural hydrological year of October to September rather than for the calendar year, the need for study of the effects of trees on rainfall and on run-off, the need for more statistical study of rainfall extremes, notably the possibility of the occurrence of extremes exceeding those adopted in design, and the value of the daily forecasts of cold spells and dry spells. Forecasts of the end of cold spells were of particular importance in minimizing waste of water from burst pipes.

Dr. H. L. Penman spoke next on components of the water balance of a catchment area illustrated by data for the Thames basin for the period 1932-36. The basic water-balance equation is that the water content of soil and rock at the beginning of a period plus rainfall during the period equals the sum of run-off and rainfall in the period and the water stored in the earth at the end. Of these quantities rainfall is the most accurately determined and run-off the next. The water in the underground storage is very difficult to determine and is probably best found as a difference from the other quantities. Evaporation is also very difficult to estimate and at present the accepted errors exceed the midsummer river-flow values. Finally Dr. Penman dealt with the effect of plants in removing water from the soil, showing that the net loss to the water engineer in this way could be equivalent to the dry-weather flow in the rivers for several months. Further, the magnitude of the soil-water deficit was a measure of the possible need for irrigation, a need which the water engineer might in the future be called on to meet at times, moreover, when other demands are greatest and supplies least.

The fifth speaker was Mr. B. J. Mason on the artificial production of rain. He said that the introduction of dry-ice, silver iodide or large water droplets from aircraft into suitable clouds had definitely shown the possibility of inducing some precipitation to occur, but large-scale work was for economic reasons possible only with silver-iodide-crystal generators on the ground. He thought there was no evidence that rainfall could be increased over large areas for long periods. In this work it was very difficult to separate variations in rainfall produced artificially from natural ones, and, further, nothing is known of the diffusion of silver-iodide particles or as to how long they remain active. He outlined his views on a suitable area for cloud-seeding trials having a line of burners across the wind between an up-wind target area and a down-wind control area. The two areas should have a high correlation of natural rainfall. He described also a method of selecting days at random for seeding using rainfall on days of no seeding as a control.

The last speaker, Dr. S. Buchan, discussed the geological aspects of underground water supply.

Some of the points raised in the discussion which followed were the validity of correlating rainfall anomalies in the target area with those over a wider area as a means of estimating the effectiveness of cloud seeding and the need for intensive observations over specially selected areas for the study of water-supply problems.

## LETTERS TO THE EDITOR

### Circular condensation trails

In his letter in your September 1954 issue, Mr. Hormbrey gives quite an accurate description of the very distinctive type of condensation trail commonly left by the B47 Stratojet. It is an important recognition feature of the aircraft, since its presence can be deduced with very little doubt at 15-20 miles distance with the naked eye in favourable conditions. The formation of the condensation trail rings can best be seen when the trail is semi-persistent (3-4 miles long), but can be recognized under conditions of persistence when the trail is not too stale.

It would perhaps be worth while to expand on some aspects of Mr. Hormbrey's description. Immediately after formation there are four separate trails, one from each engine pod, but the outer two quickly curve inwards (possibly under the influence of the wing trailing-vortex motion) and virtually join up with the corresponding inner trails. Even at this stage the cores of the two trails have a peculiarly smooth, hard appearance, with a rather diffuse "ectoplasm" which fairly quickly evaporates.

About one mile behind the aircraft the trails, which have hitherto been quite straight, begin to writhe, becoming kinked irregularly but symmetrically with respect to each other. The amplitude of the kinks increases continuously until each trail breaks up, and corresponding arcs join up to form the more-or-less complete rings described in Mr. Hormbrey's letter.



DISTRAILS SEEN OVER WEST FREUGH, STRANRAER, OCTOBER 14, 1954  
(see p. 58)



ARROW-SHAPED CLOUDS FORMED IN ASSOCIATION WITH  
THE DISTRAILS OVER WEST FREUGH, OCTOBER 14, 1954  
(see p. 58)



*Reproduced by courtesy of B. C. S. Wilson*

STRATOCUMULUS IN WAVES, CYRENAICA, MARCH 15, 1953  
(see p. 60)

I shall not offer a rival theory for this peculiar form of condensation trail, but suggest that the relevant cause is not purely meteorological. Striking regular formations of other kinds have often been observed in trails made by other aircraft types, but these are usually isolated cases which can be ascribed to special meteorological conditions. However, I have seen a Stratojet in company with a Canberra, the Stratojet forming the condensation trail typical of its kind, and the Canberra a quite indistinctive trail.

R. L. M. HARPER

*Grange Hostel, Farnborough, Hampshire, October 13, 1954*

### Upper winds over Trinidad

With the restitution of radio-sonde ascents from Chaguaramas, Trinidad ( $10^{\circ}41'N$ .  $61^{\circ}37'W$ .) in the New Year of 1954 after a break of a number of years, interest, previously stimulated by the goodwill flight of R.A.F. Canberras to South America late in 1953, was again focused on high-level winds in this area. Soundings became a regular twice-daily occurrence from January 27, 1954, and records were kept of the information received from that date until March 7, 1954. It is now of interest to inspect these data in view of the article by Bannon\* published in the September issue of the *Meteorological Magazine*.

Out of a possible 80 ascents, 60 were received during the period January 27 to March 7, 1954, all of which reached 40,000 ft. or higher, whilst 18 ascents reached over 70,000 ft. With the exception of one ascent on February 13, which is suspect, and that on March 7, when a wind of  $10^{\circ} 29$  kt. was reported, winds at 30,000 ft. during the whole period were westerly, direction varying between  $220^{\circ}$  and  $320^{\circ}$ ; and of the 58 observations at this level 47 were between  $240^{\circ}$  and  $300^{\circ}$ . The average wind speed of these 58 observations regardless of direction was 29.0 kt. while the highest recorded was 73 kt. on January 27 and 28, both at 1500 G.M.T.

At 40,000 ft. a similar flow pattern was evident, although 11 occasions of wind flow between  $180^{\circ}$  and  $210^{\circ}$  and one northerly 61 kt. have been removed from the summary. There were therefore 46 occasions of winds between  $220^{\circ}$  and  $320^{\circ}$  of which 39 were between  $240^{\circ}$  and  $300^{\circ}$ . The average speed of these 46 occasions was 35.8 kt., the maximum being 62 kt. on January 27 at 1500 G.M.T.

At 45,000 ft. a maximum of  $270^{\circ} 74$  kt. was attained on January 27 and  $290^{\circ} 79$  kt. on February 1.

At 50,000 ft. occasional light easterly winds appeared while the westerlies took on a more west-north-westerly orientation, and of 47 observations, 41 had a westerly component, 36 came from between  $220^{\circ}$  and  $320^{\circ}$  and 34 from between  $270^{\circ}$  and  $320^{\circ}$ . The average speed of these 36 occasions was 30.8 kt.

One occasion, however, has been left out of this average, that of February 25 at 0300 G.M.T. On this occasion, winds were reported as having increased from 27 kt. at 40,000 ft. to  $310^{\circ} 98$  kt. at 45,000 ft.,  $300^{\circ} 100$  kt. at 50,000 ft. and  $290^{\circ} 23$  kt. at 55,000 ft. Wind at 50,000 ft. 24 hr. previously was  $280^{\circ} 27$  kt. and 24 hr. later  $310^{\circ} 26$  kt. While sudden rather startling wind changes both in speed and direction have been observed elsewhere in these statistics, nothing

\* BANNON, J. K.; Note on the sub-tropical jet stream in January and April 1951. *Mst. Mag.*, London, 80, 1954, p. 257.

quite of this order of magnitude has been observed, and it is therefore treated with some scepticism. However, it must be stated that it was the appearance of considerable variability between winds of no more than 12 hr. apart in the early flights from Chaguaramas which prompted the compilation of the records.

Above 50,000 ft. the westerlies decreased appreciably in strength, and after a height interval of varying thickness an easterly current returned. This was not usually the case below 65,000 ft., but at 75,000 ft. 16 of the 18 observations available were between  $80^{\circ}$  and  $100^{\circ}$  while the other two were  $60^{\circ}$  and  $110^{\circ}$  respectively; wind speed had increased rapidly. The average speed of these 18 easterly winds was 27.5 kt. Still further increase in the speed of the easterly current was evident between 75,000 and 85,000 ft. At 80,000 ft.  $110^{\circ}$  45 kt. was attained on February 6,  $100^{\circ}$  40 kt. on February 17,  $90^{\circ}$  38 kt. on February 18,  $90^{\circ}$  50 kt. on February 27 and  $100^{\circ}$  47 kt. on March 4, while on March 5 a wind of  $90^{\circ}$  70 kt. was attained at the limit of the ascent, 86,000 ft. One interesting feature of the ascent of February 25, the occasion of 100-kt. westerlies, was that the easterlies freshened at a much lower level than on any other occasion, reaching  $90^{\circ}$  33 kt. at 65,000 ft. and  $80^{\circ}$  55 kt. at the limit of the ascent, 67,000 ft.

It will be noted that the stations selected in Bannon's article are all in the vicinity of the northern tropic with the exception of Albrook Field in the Panama Canal Zone and Dakar. Albrook Field is on the approximate latitude of Trinidad, while Dakar is some  $4^{\circ}$  further north, but the point stressed here is that strong westerly winds are still well in evidence as close as  $10^{\circ}$  from the geographic equator and on occasion may increase to jet-stream proportions.

The flow during the period under consideration is marked by three maxima in the westerly current, between January 27 and February 1, on February 19, and between February 28 and March 4; on each occasion westerlies at some level attained a speed in excess of 50 kt. On the first two occasions the synoptic charts prepared at Trinidad indicated the polar front near or a little south of Bermuda, but on both occasions a trough existed ahead of it over the area of the Lesser Antilles, and on the first occasion this trough moved north-north-east or north-east and developed into a small low near the Azores. On the third occasion, a series of deep depressions occurred over the eastern United States and, although outbreaks of cold air occurred in the Gulf of Mexico and possibly also in the western Caribbean, there was little evidence of cold air further east or south-eastwards.

P. S. GRIFFITHS

*Meteorological Office, Piarco Airport, Trinidad, November 9, 1954*

### **Distrails**

On the morning of October 14 a Lincoln aircraft was carrying out bombing trials over Luce Bay between 1100 and 1200 G.M.T. at an altitude of 18,000 ft. From the ground it appeared that the aircraft was at times flying into a thin cloud layer, which was being reported at West Freugh as high altocumulus. Whilst flying in this cloud layer the aircraft was leaving a very distinct distrail. The photographs facing pp. 56 and 57 were taken at approximately 1155 G.M.T., and the weather conditions were as follows: visibility 40 miles, trace of cumulus base 2,000 ft., 3 oktas of altocumulus base 18,000 ft., thin cirrus above, total cloud amount 4 oktas.



After the aircraft had completed about five runs over the target area the arrow-shaped white cloud near the centre of the photograph began to form near the first distrail. It seems possible this cloud was produced in some way by the distrails, as it was completely isolated from the main cloud layer and appeared to be thicker. Its structure resembled an X-ray plate of the human chest. About fifteen minutes later the altocumulus cloud inside the distrails in the top right-hand corner of the photograph appeared to have *virga* below them. A second arrow-shaped cloud, shown towards the top right corner began to form but did not develop to so large a cloud as the first one.

J. M. STUART

*West Freugh, November 20, 1954*

[It seems likely the cloud in which the distrails were found was composed of supercooled water drops, and that the passage of the aircraft produced a form of ice-crystal seeding either by causing the drops near its path to freeze by turbulence or by shedding rime from its wings. The rapid growth of the crystals would cause them to fall out of the cloud layer leaving a clear lane through the cloud which would only slowly fill up by lateral diffusion. On this basis the denser arrow-shaped cloud would be composed of falling ice crystals and the reference to *virga* would appear to confirm this.

A similar effect has been produced in stratocumulus cloud by dry-ice seeding from a Meteorological Research Flight aircraft. Vertical wind shear would help to give the falling crystals an apparent lateral spread when viewed from the ground.

This explanation would not be satisfactory if the distrail formed immediately behind the aircraft, in which case the explanation of distrail formation given by Dr. Scorer\* of evaporation of the water drops by exhaust heating would be the more likely. Dr. Scorer's theory would not account for the formation of the arrow-shaped clouds.—R. F. JONES.]

## NOTES AND NEWS

### Kew, Makerstoun and Eskdalemuir Observatories

The account of the unveiling of the memorial tablets at Kew in the November issue recalls the Makerstoun Magnetic Observatory on the banks of the Tweed, for John Welsh received his training there under John Allan Broun, F.R.S.

The Makerstoun Observatory was erected by General Sir Thomas Makdougall Brisbane in 1841 and its observations were published in detail in the *Transactions of the Royal Society of Edinburgh* until 1855. A Mr. Russell was the first director, but J. A. Broun succeeded him within a year and shortly obtained the appointment of John Welsh as his assistant. After the departure of Welsh to Kew in 1850 and of Broun to Travancore in 1851, the editing of the Makerstoun results was carried out by Balfour Stewart at Kew. A successor of Broun at Travancore was Dr. A. Crichton Mitchell who later was in charge of Eskdalemuir Observatory some 30 miles south-west of Makerstoun.

\* SCORER, R. S.; Contrails and distrails. *Met. Mag., London*, 82, 1953, p. 27.

### **Cirrocumulus cloud at Cranwell**

The photographs of cirrocumulus cloud facing pp. 40 and 41 were taken at Cranwell at 1600 G.M.T. on November 15, 1954. The development of the cloud was watched by Messrs. Blackham, Clarke and Mason of the meteorological office at Cranwell during the afternoon as it increased from 1 okta at 1300 to 3 oktas in the south-west at 1600 G.M.T.; the weather was fine throughout.

The 1200 G.M.T. chart on that day showed a warm front along the east Irish coast, with an anticyclone centred over the Midlands. Rain associated with the warm front began at Cranwell at 2340 G.M.T.

### **Working exhibit of smoke-pollution sampling equipment at the Science Museum, South Kensington**

An observing station for measuring the smoke and sulphur-dioxide pollution in the London atmosphere has been established in the Science Museum by co-operation with the Fuel Research Station of the Department of Scientific and Industrial Research. The station is one of a number that are being established to permit a more detailed examination of atmospheric pollution in London and elsewhere.

The sampling equipment is displayed as a working exhibit in the Meteorology gallery. The smoke particles are captured on filter paper through which air is drawn, from just above the museum roof level, by means of a small electric pump. As a result, a grey stain appears on the filter paper, the intensity of which is a measure of the degree of smoke pollution. The same air is bubbled through a weak solution of hydrogen peroxide where the atmospheric sulphur dioxide is dissolved to form an acid solution, the strength of which is measured by standard chemical methods.

### **Stratocumulus in waves**

The lower photograph facing p. 57 was taken by Mr. B. C. S. Wilson from the cemetery of Sidi Ubeida on the main road from Benghazi to Benina in Cyrenaica on March 15, 1953, about midday. The cloud was associated with a weakening cold front extending from Greece to the Gulf of Sidra and thence westwards as the warm front of a depression moving eastwards across Algeria.

During March 15 the surface wind was gusty and increasing from the east, reaching gale force during the afternoon; there was intermittent slight rain at 1520. At 6,000 ft. (800 mb.) the wind was little more than 20 kt. but from the south-west; and the radar-wind ascents from Benina showed a wind shear at about the level of the cloud increasing from 305° 18 kt. at 0200 to 290° 32 kt. at 1515 G.M.T. Since the photograph was taken looking approximately northwards the waves can be seen to be roughly at right angles to the direction of the wind shear.

### **Council for the Promotion of Field Studies**

The Council have recently published details of their courses for 1955. The courses include one on the physical basis of meteorology with special reference to current weather to be held at the Malham Tarn Field Centre (near Settle,

Yorkshire) during August 24-31. The meteorological offices at Preston and Squires Gate assist in the instruction at Malham Tarn by providing data for plotting synoptic charts and by discussing current weather and forecasts.

Further particulars may be obtained from the Council at Balfour House, Finsbury Pavement, London, E.C.2.

### REVIEW

*Klima und Wetter in Arosa.* By Prof. Dr. F. W. Paul Götz, 9½ in. × 7½ in., pp. 148, *Illus.*, Verlag Huber & Co., Ag., Frauenfeld, 1954. *Leinen Fr.* 18.70; *DM* 18.

In this beautifully produced volume Dr. Götz gives a very detailed and vivid description of the climate and weather of Arosa in eastern Switzerland based on observations made since 1890. Separate chapters cover temperature, dryness of the air, atmospheric purity and ozone content, wind, cloudiness, precipitation and snow-cover, sunshine and radiation. Finally, there is a chapter on the variations in weather through the year, and on secular changes in climate. Each chapter contains a large number of tables and curves of mean values and variations of the element concerned. There are a number of good photographs of the observing station, instruments, clouds and optical phenomena.

The variations of the elements are treated in relation to the synoptic situation. For example, interdiurnal variability of temperature is connected with air-mass changes. The book is an excellent example of a treatise on synoptic climatology as well as on climatology.

The radiation climate of Arosa merits special mention. The mean annual duration of bright sunshine is 1,900 hr., 51 per cent. of the possible, and the mean annual global radiation is 127 Kg. cal./cm.<sup>2</sup>, values which are of the order of 1.4 times those for Kew.

The secular variation of each element is described with 10-yr. overlapping means. It is particularly interesting to compare the curves for the separate elements. The secular variation of temperature over the last century has been much discussed, but the reviewer believes this book affords one of the first opportunities of comparing the secular variations of several elements. Curves of 10-yr. overlapping means of temperature are given for the year, and the winter and summer half-years. All are roughly parallel. The 10-yr. overlapping means for the year show a fall from about 2.8°C. for periods terminating about 1900 to 2.4°C. for those terminating about 1910 followed by a rise to a peak of 3.2°C. for 1920-29, after which period there has been an irregular mainly falling tendency down to 2.8°C. for the 10 yr. ending in 1945.

The secular variations of the frequency of occasions of interdiurnal changes of temperature exceeding 5°C. for winter and spring provide curves which are roughly the inverse of those for temperature. The summer and autumn curves have less marked changes and show on the whole a rise throughout.

Cloudiness had a secular variation roughly the inverse of the variation of temperature. The 10-yr. mean was 5.4 tenths in 1891-1900. The value rose to 5.6 tenths in 1903-12 and fell to 5.4 tenths in 1912-21. The means have since risen and the value for 1936-45 was 6.3 tenths. The variation has been

very similar in all seasons and is shown to have been the same over the whole of Switzerland. The 10-yr. overlapping means of annual precipitation rose from about 1,200 mm. for the period 1891-1900 to 1,400 mm. for 1909-19 since when there has been a very irregular fall.

Summarizing the secular variation of climate Dr. Götz shows that about the turn of the century the climate became more maritime in nature followed by a return to a more continental type in the last ten years.

G. A. BULL

### HONOURS

The following awards were announced in the New Year Honours List, 1955:—

#### KNIGHT BACHELOR

Dr. O. G. Sutton, C.B.E., F.R.S., Director of the Meteorological Office.

O.B.E.

Mr. H. W. L. Absalom, Assistant Director, Meteorological Office.

M.B.E.

Miss L. F. Lewis, Experimental Officer, Meteorological Office.

Mr. H. L. Pace, Senior Experimental Officer, Meteorological Office.

B.E.M.

Mr. H. A. Curtis, Senior Scientific Assistant, Meteorological Office.

### OBITUARY

*Mr. Terence Brady.*—We regret to announce the death of Mr. Brady, Senior Scientific Assistant, as a result of the accident to the British Overseas Airways Corporation aircraft at Prestwick on December 25, 1954. Mr. Brady joined the Office in 1941 and the whole of his service was spent at outstations. After a tour of duty in the West Indies, he served alternately at Prestwick and London airports. It was from London Airport that Mr. Brady was travelling home to Scotland on Christmas leave when the accident occurred.

### METEOROLOGICAL OFFICE NEWS

**Award.**—It was announced in the *London Gazette* of November 26, 1954 that Mr. R. A. Hamilton, Principal Scientific Officer, had been awarded a Clasp to his Polar Medal for good services with the British North Greenland Expedition 1952-54 as Chief Scientist and Second-in-Command, 1952-53. Mr. Hamilton was previously awarded a Polar Medal for services with the Oxford University Arctic Expedition to North East Land in 1935-36.

**Retirement.**—Mr. C. Smith, Senior Experimental Officer, retired on December 31, 1954. He joined the Office in 1920 after service during the First World War in the West Yorkshire Regiment and as Observer in the Royal Flying Corps, when he was shot down and captured. During his 34 years' service, Mr. Smith has served both at Headquarters and at aviation outstations, including two tours of duty overseas in the Middle East. From 1946 until his retirement he served at Headquarters in the branch dealing with the Royal Air Force Overseas.

## WEATHER OF DECEMBER 1954

Mean pressure was below normal between Greenland and Scandinavia, as much as 13 mb. in places between Iceland and Norway but generally about 8 mb. At the Azores the mean pressure was 3 mb. above normal. The resulting mean pressure distribution was associated with westerly winds across the Atlantic and western Europe. The mean pressure over the central region of Russia was about 10.44 mb.; this was about 8 mb. above normal.

The mean temperature was above normal over the whole of western Europe, generally 5-4°F. but as much as 9-10°F. in northern Scandinavia.

In the British Isles the weather was mainly stormy and mild though there was a colder period from about the 5th to the 12th or 13th. In the south the second half of the month was mainly dry.

During the first few days depressions moved east-north-east across the North Atlantic and passed between Iceland and Scotland giving unusually mild weather; on the 2nd temperature reached between 55° and 60°F. over almost the whole country. There was frequent rain, heavy at times in the north and west; for example, 3.35 in. at Borrowdale, Cumberland, 3.24 in. at Ribbleshead, Yorkshire and at Patterdale, Westmorland, and 2.01 in. at Glenshiel, Ross and Cromarty on the 1st, 2.94 in. at Oakley Quarries, Merionethshire and 2.91 in. at Corris, Montgomeryshire on the 2nd and 2.43 in. at Glenquoich, Inverness-shire on the 3rd. On the 4th a depression crossed northern Scotland and was accompanied by north-westerly gales over much of the country, a gust of 85 kt. being recorded at Harlech in north Wales. Temperature fell with the influx of the north-westerly winds. Subsequently the track of depressions veered and on the 6th and 7th a weak system moved south-east across the British Isles bringing snow as far south as southern England. On the 8th a depression on a parallel track deepened off Ireland, moved towards Wales and crossed northern England and Scotland on the 9th and 10th giving widespread and severe gales. There was heavy rain, particularly in the south and east, on the 8th and moderate rain locally in the north on the 9th. Thunderstorms occurred rather widely in the south and east on the 8th, and were associated with heavy rain, hailstones up to 1 in. in diameter, and minor tornadoes locally in south-east England including the west London area, where there was considerable damage to buildings; 2.09 in. was registered at Princes Risborough, Buckinghamshire. The period 5th to 12th or 13th was generally rather cold; at Eskdalemuir temperature remained below freezing point throughout the day on the 7th. With the departure of this deep depression less active systems travelled across the Atlantic to the British Isles; unsettled weather persisted until the 14th with some rain in most places every day. The 14th was sunless over almost the whole country though temperature rose to 55°F. in places. For most of the third week an anticyclone extended from west to east across Europe and frontal activity was confined mainly to western and northern districts (2.75 in. of rain fell at Glenquoich on the 17th and 2.15 in. at Glenshiel on the 18th). In the south there were sunny periods but a good deal of fog, particularly during the nights of the 15th, 16th and 17th. From the 20th the dominant system was an anticyclone which came from America and intensified to west-south-west of the British Isles; on the 21st, however, a deep depression moving round it from Iceland towards Denmark brought a period of rather cold, locally severe, north-westerly gales over most of the country and a gust of 90 kt. at Kinloss in north-east Scotland. Rain or showers occurred in most places and on the 22nd rainfall was heavy in Argyllshire and inland in north Wales; for example, 2.30 in. at Dalnes and 2.22 in. at Llangurig, Montgomeryshire. From the 25th to the 29th the anticyclone off our south-west coasts moved very slowly east and mild air from the Azores region spread to all districts; weather was mainly dull and also dry in the south but with heavy rain at times in the north (2.10 in. at Corrykinloch, Sutherland on the 28th). By the 30th the anticyclone over Germany had linked up with high pressure over Scandinavia and there was little rain anywhere except on the south-west coasts of Ireland.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	62	17	+3.6	89	-2	108
Scotland ...	59	12	+1.9	137	+4	80
Northern Ireland ...	58	29	+3.2	120	+3	58



# RAINFALL OF DECEMBER 1954

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	1.57	66	<i>Glam.</i>	Cardiff, Penylan ...	3.92	76
<i>Kent</i>	Dover ...	1.39	45	<i>Pemb.</i>	Tenby ...	3.73	75
	Edenbridge, Falconhurst ...	2.12	64	<i>Radnor</i>	Tyrmynydd ...	7.10	86
<i>Sussex</i>	Compton, Compton Ho. ...	3.88	94	<i>Mont.</i>	Lake Vyrnwy ...	7.79	110
	Worthing, Beach Ho. Pk. ...	2.64	88	<i>Mer.</i>	Blaenau Festiniog ...	16.48	130
<i>Hants.</i>	Ventnor Park ...	3.47	103		Aberdovey ...	6.19	130
	Southampton (East Pk.) ...	2.92	80	<i>Carn.</i>	Llandudno ...	2.51	87
	South Farndoroug ...	2.49	86	<i>Angl.</i>	Llanerchymedd ...	3.32	76
<i>Herts.</i>	Royaston, Therfield Rec. ...	1.65	71	<i>I. Man</i>	Douglas, Borough Cem. ...	7.20	148
<i>Bucks.</i>	Slough, Upton ...	2.01	80	<i>Wigtown</i>	Newton Stewart ...	6.59	122
<i>Oxford</i>	Oxford, Radcliffe ...	2.02	82	<i>Dumf.</i>	Dumfries, Crichton R.I. ...	4.28	100
<i>N'hants.</i>	Wellingboro' Swanspool ...	2.59	110		Ekdalemuir Obsy. ...	8.61	123
<i>Essex</i>	Shoeburyness ...	1.10	60	<i>Roxb.</i>	Crailling ...	2.62	97
	Dovercourt ...	1.48	69	<i>Peebles</i>	Stobo Castle ...	5.17	106
<i>Suffolk</i>	Lowestoft Sec. School ...	1.54	66	<i>Berwick</i>	Marchmont House ...	2.39	85
	Bury St. Ed., Westley H. ...	2.25	93	<i>E. Loth.</i>	North Berwick ...	1.75	82
<i>Norfolk</i>	Sandringham Ho. Gdns. ...	2.16	85	<i>Midl'n.</i>	Edinburgh, Blackf'd. H. ...	2.67	114
<i>Wilts.</i>	Aldbourne ...	3.02	93	<i>Lanark</i>	Hamilton W. W., T'nhill ...	6.05	140
<i>Dorset</i>	Creech Grange ...	3.77	85	<i>Ayr</i>	Colmonell, Knockdolian ...	...	...
	Beaminster, East St. ...	3.63	76		Glen Afton, Ayr San. ...	9.35	146
<i>Devon</i>	Teignmouth, Den Gdns. ...	3.41	81	<i>Renfrew</i>	Greenock, Prospect Hill ...	8.71	117
	Ilfracombe ...	4.45	92	<i>Bute</i>	Rothsay, Ardenraig ...	6.05	111
	Princetown ...	8.39	72	<i>Argyll</i>	Morven, Drimmin ...	8.73	111
<i>Cornwall</i>	Bude, School House ...	2.98	68		Poltalloch ...	10.97	178
	Penzance ...	4.70	83		Inveraray Castle ...	17.34	175
	St. Austell ...	5.39	88		Islay, Eallabus ...	6.15	104
	Scilly, Tresco Abbey ...	3.64	78		Tiree ...	5.55	108
<i>Somerset</i>	Taunton ...	2.43	73	<i>Kinross</i>	Loch Leven Shuice ...	4.32	110
<i>Glos.</i>	Cirencester ...	2.55	76	<i>Fife</i>	Leuchars Airfield ...	3.02	122
<i>Salop.</i>	Church Stretton ...	2.74	78	<i>Perth</i>	Loch Dhu ...	13.77	137
	Shrewsbury, Monkmore ...	1.90	78		Crief, Strathearn Hyd. ...	6.00	134
<i>Worcs.</i>	Malvern, Free Library ...	1.66	60		Pitlochry, Fincastle ...	6.12	151
<i>Warwick</i>	Birmingham, Edgbaston ...	2.35	87	<i>Angus</i>	Montrose, Sunnyside ...	2.58	92
<i>Leics.</i>	Thornton Reservoir ...	2.77	103	<i>Aberd.</i>	Braemar ...	6.27	176
<i>Lincs.</i>	Boston, Skirbeck ...	2.23	104		Dyce, Craibstone ...	3.35	99
	Skegness, Marine Gdns. ...	1.58	72		New Deer School House ...	5.13	150
<i>Noths.</i>	Mansfield, Carr Bank ...	...	...	<i>Moray</i>	Gordon Castle ...	4.07	151
<i>Derby</i>	Buxton, Terrace Slopes ...	8.24	145	<i>Nairn</i>	Nairn, Achareidh ...	3.64	176
<i>Ches.</i>	Bidston Observatory ...	2.74	103	<i>Inverness</i>	Loch Ness, Garthbeg ...	8.45	183
	Manchester, Ringway ...	5.02	155		Glenquoich ...	25.06	171
<i>Lancs.</i>	Stonyhurst College ...	6.71	138		Fort William, Teviot ...	16.33	160
	Squires Gate ...	3.71	119		Skye, Broadford ...	...	...
<i>Yorks.</i>	Wakefield, Clarence Pk. ...	2.38	98		Skye, Duntuil ...	5.99	96
	Hull, Pearson Park ...	2.24	93	<i>R. &amp; C.</i>	Tain, Mayfield ...	4.92	173
	Felixkirk, Mt. St. John ...	2.19	91		Inverbroom, Glackour ...	...	...
	York Museum ...	1.97	88		Achnashellach ...	15.47	163
	Scarborough ...	1.64	69	<i>Suth.</i>	Lochinver, Bank Ho. ...	6.78	122
	Middlesbrough ...	1.69	87	<i>Caith.</i>	Wick Airfield ...	5.49	176
	Baldersdale, Hury Res. ...	4.67	121	<i>Shetland</i>	Lerwick Observatory ...	6.13	128
<i>Nor'l.d.</i>	Newcastle, Leazes Pk. ...	1.80	77	<i>Fern.</i>	Crom Castle ...	4.00	97
	Bellingham, High Green ...	4.10	113	<i>Armagh</i>	Armagh Observatory ...	3.73	119
	Lilburn Tower Gdns. ...	2.45	93	<i>Down</i>	Seaforde ...	4.81	117
<i>Cumb.</i>	Geltsdale ...	5.01	131	<i>Antrim</i>	Alldergrove Airfield ...	3.74	109
	Keswick, High Hill ...	8.46	126		Ballymena, Harryville ...	6.04	196
	Ravenglass, The Grove ...	4.68	102	<i>L'derry</i>	Garvagh, Moneydig ...	...	...
<i>Mon.</i>	A'gavenny, Plás Derwen ...	3.31	67		Londonderry, Creggan ...	5.79	132
<i>Glam.</i>	Ystalyfera, Wern House ...	7.15	86	<i>Tyrone</i>	Omagh, Edenfel ...	5.42	128

Printed in Great Britain under the authority of Her Majesty's Stationery Office  
By Geo. Gibbons Ltd., Leicester